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FY20 Progress Report on FIPD Development and User Support

Chemical and Fuel Cycle Technologies Division

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FY20 Progress Report on FIPD Development and User Support

prepared by
A. Oaks, K. Mo, Y. Miao, A. M. Yacout
Chemical & Fuel Cycle Technologies Division, Argonne National Laboratory

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Summary

FY20 Progress Report on FIPD Development and User Support

The DOE Advanced Reactor Technologies program has supported efforts to recover and preserve metallic fuel data generated throughout the past fast reactor R&D programs. Those efforts have focused on establishing databases for information from the experiments conducted during the Integral Fast Reactor program including data generated at EBR-II, FFTF, and TREAT reactors, as well as out of pile transient testing data. These databases are essential for future-licensing activities of metallic fuel based advanced fast reactors. This report describes the EBR-II Fuels Irradiation & Physics Database (FIPD) development, content updates, and user support during the current fiscal year (FY20). Future plans are also provided.

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1 INTRODUCTION

The majority of sodium-cooled fast reactor (SFR) fuels knowledge in the US comes from data collected at the Experimental Breeder Reactor II (EBR-II) and the Fast Flux Test Facility (FFTF) reactors during their operations starting in the early 1960's for EBR-II and 1984 for FFTF until their shutdown. This experience generated data for both metallic and oxide fuels. In particular, U-Zr based metallic alloy fuel data were generated during the integral fast reactor (IFR) program as well as oxide fuel data generated at FFTF and during the oxide fuels testing program at EBR-II. This legacy knowledge base includes general reactor information, old Argonne reports, IFR program reports, EBR-II run reports, memos, post irradiation examinations (PIE), drawings, experiments qualification reports, publications in journals and conferences, information regarding measured properties (e.g., IFR metallic fuels handbook), and documents of out of pile experiments. Also, measurement documents like micrographs, profilometry data, fission gas release data complement the other available metadata. During the later stages of the IFR program (early 1990s), there was an effort on development of the IFR Material Information System (IMIS) that intended to assemble this information set in a database [1]; however, it was not completed due to abrupt termination of the IFR program in 1994. In particular, detailed data associated with each fuel pin in those experiments (irradiation history) and its association with fabrication and PIE data was not fully archived. This detailed information is mostly based on a combination of physics and thermal hydraulic information that are generated using reactor run operations data and fuel fabrication information. Other information (e.g., general properties data in the IFR fuels handbook, code calculations, etc.) are not currently available in an accessible form that can facilitate its use by interested analysts.

1.1 Motivation

The above accumulated knowledge represents a large U.S. investment in advanced fast reactor research and development, provides a wealth of information to different groups of interest, and needs to be well archived and maintained so it is easily accessed and utilized in the future by the industry and the NRC. Preserving this detailed fuel and physics knowledge enables the support to reactor designers in their design and safety assurance of the advanced fast reactor concepts they pursue. It also supports reactor vendors (and utilities) in their effort to make a licensing case for the concepts using similar fuel forms. In addition, detailed in-reactor database information on fuel performance supports the analysts in understand fuel behavior and supporting the development and validation of advanced fuel performance codes for design and licensing purposes.

A fast reactor metallic fuels database that compiles accurate and detailed operating and performance parameters is important to industry who have shown interest in developing metallic fuel based fast reactors (e.g., Terrapower, GE-H, Oklo and ARC). These stakeholders have expressed interest in establishing a safety case for this type of fuel within a given operations envelope in a commercial reactor. Such a database can also be used for demonstrating to the licensing authorities the availability of a well-established database that supports safe reactor operations. In addition, the industry and other stakeholders (e.g., NRC and DOE-NE's Versatile Test Reactor (VTR) project) have an active interest in developing and validating the existing or emerging fuel performance computer codes using the most accurate set of data that provides best estimate descriptions of fuel behavior in a fast reactor. Well validated code calculations can be used for the purposes of core design, safety analysis, reactor operations, and satisfying licensing requirements. In general, the database discussed in this report is designed to provide such accurate and detailed fuel irradiation and physics data needed for support of future design and licensing activities of metallic fuels based fast reactors.

1.2 Background

Since its start, EBR-II hosted experiments in support of different US fast reactor programs to test the behavior and performance of different types of fuels including metallic, oxide, mixed oxide, and mixed carbide fuels. A wealth of information was generated from those experiments, however most of the existing metallic fuels database is associated with the IFR program, which ran from 1984 to 1994. The IFR metallic fuel experiments looked at one or more of the following:

- prototypic fuel behavior
- run beyond cladding breach behavior (RBCB)
- fuel swelling and restructuring
- lead IFR experiment
- fabrication parameters
- design parameters
- high temperature behavior
- large slug diameter
- blanket safety
- fuel qualification
- fuel impurities

PIE data from those experiments included fission gas release, fuel volumetric and fuel length change, cladding diametral change, and cladding wastage. Axial profiles are available for fuel radial growth at low burnup (prior to and including initial fuel-cladding contact) and for cladding radial growth for a wide range of burnups and fast fluences. Some data that are available on a more limited basis are radial and axial variations in U, Pu, Zr; fission gas porosity; axial variations in fraction of porosity filled (logged) with Na; as well as the depth of C-depleted and Ni-depleted zones in HT9 and D9 cladding materials, respectively. The intent of this database effort was to create a web-accessible relational database as an archive of information from EBR-II fuels irradiation experiments, combine it with other forms of information that are based on calculations, and make it available in a form that is appropriate for use by fuels and reactors analysts/modelers.

The database development is an ongoing effort over the past few years [1, 2, 3, 4, 5, 6, 7], and continues to the present (FY20). The FY20 improvements to the database structure, interface, and content are described in the subsequent sections.

2 DATABASE CONTENT ADDITIONS

This section describes additions and improvements to the content of the database. Improvements to the web interface are discussed in a later section.

2.1 Operating Parameters

The pin-level operating parameters available in FIPD are summarized below in Figure 1. These parameters are calculated using a series of computational codes, described in more detail in a previous report [7].

Temperatures	Power/Burnup	Isotope Densities
•Coolant flow	•Linear power	•Uranium (U-234, U-235, U-236, U-238)
•Cladding outer surface	•Power density	•Neptunium (Np-237)
•Cladding midwall	•Cycle DPA	•Plutonium (Pu-236, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242)
•Cladding inner surface	•Burnup	•Americium (Am-242, Am-243)
•Fuel outer surface	•Fast fluence	•Curium (Cm-242, Cm-254, Cm-244, Cm-245, Cm-246)
•Fuel centerline	•Total fluence	

Figure 1: Calculated data available in FIPD. Data are given as axial distributions for each pin in the assembly.

The linear power of each fuel pin is provided at 30 equally spaced axial locations for each EBR-II run. For each run, the beginning and ending calendar dates were used to calculate the duration of that run (termed "RCT run duration", as it is initially adopted by the RCT code). The power of the pin reported for a run is the time-average value calculated by dividing the deposited energy by the RCT run duration. This approach had two notable drawbacks: (1) using the calendar days for run time becomes less accurate for very short runs that are on the order of one day in length, as well as in runs that contain zero-power periods within the run, and (2) using the average power level can leave out key fuel performance phenomena that could be triggered or enhanced by above-average peak temperatures experienced during a run.

To achieve a more accurate representation of average power, each EBR-II run history was reviewed, and corrected run times were determined which excluded zero-power segments of the run history. This included both before and after run times within the calendar days when the run was started and stopped, as well as any zero-power periods that occurred during the run. The corrected-average power level and run time were then used to calculate a power scaling factor that could be applied to the original RCT data. The thermal calculations were repeated using this scaling factor to produce linear power and temperatures that more accurately correspond to the average power condition of the run. These results are provided in FIPD as "corrected-average" thermal results, alongside the original thermal results for comparison.

Similarly, to facilitate simulations with sensitivity to peak temperature, each EBR-II run was reviewed to determine the maximum power of the run. The effective maximum power time (EMPT) was then calculated to produce the same total energy deposition from running at the maximum power. The EMPT thermal results were calculated with the max power and EMPT the same way as the corrected-average results discussed above. These results are provided in FIPD as "EMPT" results, alongside the original and corrected-average results for comparison. An example comparison of these three cases is shown in Figure 4.

Both "corrected-average" and "EMPT" thermal results have been calculated and are currently available for all pins in all 641 subassembly/run configurations.

2.2 Measured Data

In FY20, various types of PIE data available in the FIPD source library were reviewed, analyzed, digitized and assessed, including contact and laser profilometry, and isotopic gamma scans. The collection of more PIE data has also continued in FY20. More than 300 neutron radiography (NRAD) scans (in 9 subassemblies) have been received from Idaho National Laboratory (INL) and incorporated into FIPD after reviewing and processing. These additions to the PIE data available in FIPD are summarized in the following sections.

2.2.1 Digitized Contact Profilometry Data

The contact profilometry data is considered one of the most important PIE datasets for engineering applications and safety analysis, particularly for analyzing the fuel-cladding mechanical interaction (FCMI) behavior in metallic fuel [8]. The contact profilometry measurements were performed as a non-destructive examination of the cladding dimensional changes, using an electronic gauge to measure the diameter profile of a fuel element continuously over the region of interest [9]. The contact profilometer did not output digital signals, and all measured data was recorded on paper data record sheets (with grids) during the measurements. After the measurement, the original/raw data record sheet were copied, and later scanned into PDF files that are now stored in the FIPD library. The quality of these scans (e.g. contrast and resolution of the data sheets) varies between different experiments. Direct use of the images in PDF format is impractical for engineering design, fuel performance modeling and safety analysis. Therefore, data digitization of electronic "hard-copy" data is necessary to allow users to reuse the profilometry/strain data for further analyses. To date, all available contact profilometry data in FIPD has been digitized using the Fast Reactor Data Digitalization System (FRDDS) code [6]. Detailed descriptions of the digitization process can be found in ref. [7]. However, for quality assurance purposes, both hard-copy and digitized data need to be examined by a subject matter expert (SME) before adding the data to the database [10]. As of the current reporting period, 16 experiments have been reviewed and added to the database, and a total of 551 digitized profilometry datasets were stored in the database, all of which are now accessible by FIPD users. Table 1 summarized the current archival status of the contact profilometry data. More than 100 digitized contact profilometry datasets from X421/X421A, X441/X441A, and X486 experiments were recently employed by users at INL to compare with results of BISON simulations [11].

Table 1: Current archival status of the contact profilometry data.

Experiment	Number of Images in Hard Copy	Number of Hard-copy Datasets Examined by SME	Number of Digitized Images	Number of Digitized Datasets Examined by SME	Number of Datasets Available in FIPD
X419	61	61	61	61	61
X419A	9	9	9	9	9
X419B	60	60	60	60	60
X420A	57	57	57	57	57
X420B	1	-	1	-	-
X421	61	61	61	61	61
X421A	7	7	7	7	7
X423	6	6	6	6	6
X423A	6	6	6	6	6
X423B	9	9	9	9	9
X423C	37	37	37	37	37
X425A	60	-	60	-	-
X425B	59	-	59	-	-
X425C	60	-	60	-	-
X430	37	37	37	37	37
X430B	37	37	37	37	37
X435	16	-	16	-	-
X441	61	61	61	61	61
X441A	50	50	50	50	50
X447A	47	47	47	47	47
X448	7	-	7	-	-
X452A	23	23	23	-	-
X482A	1	-	1	-	-
X482B	1	-	1	-	-
X483	7	-	7	-	-
X486	6	6	6	6	6
X489	7	-	7	-	-
X492	5	-	5	-	-
Total:	798	574	798	551	551

2.2.2. Digitized Laser Profilometry Data

Complementary to contact profilometry measurements, laser profilometry measurements provide high-quality data of cladding dimensional changes. The "high-quality" herein refers to a data plot/curve with a better contrast to the background and less fluctuation, and contains more data points. Typical laser profilometry data of a fuel element contains multiple measurements at different scanning angles for one single fuel element. For example, pin DP17 in X441 was measured at 21 angles (with 9 degree spacing: 0, 9º, 18º…180º). Therefore, even though the number of available fuel pins with laser profilometry (only 82 pins in FIPD) is much smaller than that of contact profilometry (798 pins), the actual number of datasets of laser profilometry (1105 sets) is more than that of contact profilometry (798 sets). Most of electronic "hard-copy" laser profilometry data (over 1000 datasets) have been digitized using the FRDDS [6]. The current archival status of the laser profilometry data is summarized in Table 2. Similar to the contact profilometry data, both hard-copy and digitized data need to be examined by an SME before being added to the database [10]. As of the current reporting period, 420 datasets have been reviewed, and 231 datasets have been added to the database.

Table 2: Current archival status of the laser profilometry data.

Experiment	Number of Pins in Hard Copy	Number of Images in Hard Copy	Number of Hard-copy Datasets Examined by SME	Number of Digitized Images	Number of Digitized Datasets Examined by SME	Number of Datasets Available in FIPD
X419B	4	27	-	27	-	-
X420A	5	25	-	25	-	-
X420B	14	199	-	199	-	-
X421	8	10	-	10	-	-
X421A	17	168	-	168	-	-
X425	1	5	-	5	-	-
X429	1	1	-	1	-	-
X429B	1	5	-	5	-	-
X431	1	40	-	-	-	-
X435	2	15		15	-	-
X441	11	231	231	231	231	231
X441A	10	175	175	175	175	-
X447	2	14	14	14	14	-
X447A	5	190	-	190	-	-
Total:	82	1105	420	1065	420	231

2.2.3 Digitized Gamma Scan Data

Among all types of PIE data, the amount of isotopic gamma scan data is the largest in terms of the number of scanned images in archived documentation. The isotopic gamma scan data of each fuel element usually contain the data for specific isotopes (e.g., Cs-134, Cs-137, Mn-54, Nb-95, Rh-106, and Zr-95), and a measurement of gross activity. All of the isotopic gamma scan legacy data were preserved in hard-copy record sheets, and have been scanned into PDF files which were uploaded and stored in the FIPD library. Similar to the profilometry data, the digitization of the gamma scan hard-copy files was performed using FRDDS. Over 3000 datasets/images have been digitized up to the date of reporting. All the digitized data needs to be reviewed by an SME before adding to the database [10]. If inconsistencies are found during the SME review between the raw and digitized data, the issues would be recorded, and re-digitization for the data with issues would be performed to ensure the quality of digitized data. As of the current reporting period, 15 experiments have been examined by the SME. Eleven experiments were approved by the SME to add to the database. Inconsistencies were found in some datasets in X420, X420A, X420B, and X421A experiments, and those datasets were re-digitized and uploaded to FIPD. As of the current reporting period, a total of 1434 digitized gamma scan datasets are accessible in FIPD. Table 3 summarized the current archival status of the isotopic gamma scan data.

Table 3: Current archival status of the isotopic gamma scan data.

Experiment	Number of images in hard copy	Number of Digitized images	Number of Datasets Examined by SME	Number of Datasets Available in FIPD
X419	378	378	378	378
X419A	125	125	125	125
X419B	27	27	27	27
X420	154	154	154	-
X420A	91	91	91	-
X420B	170	170	170	-
X421	217	217	-	-
X421A	163	163	163	-
X423	42	-	-	-
X423A	73	-	-	-
X423B	121	-	-	-
X423C	285	285	-	-
X425	149	149	-	-
X425B	248	248	-	-
X425C	110	110	-	-
X430B	49	49	-	-
X431	65	65	65	65
X435	202	202	-	-
X441	277	277	277	277

X441A	240	240	-	-
X447	3	3	-	-
X447A	91	91	91	91
X448	119	119	119	119
X482A	17	17	-	-
X482B	14	14	-	-
X483	105	105	105	105
X489	118	118	118	118
X492	93	93	93	93
X492A	32	32	32	32
Total	3778	3542	1434	1434

2.2.4 Neutron Radiography Scans

Neutron radiography (NRAD) is a unique PIE for analyzing fuel swelling in both axial and radial directions. In past versions of FIPD library (FY19 and before), only a small subset of experiments contained NRAD data, and their resolution was not sufficient to perform quantitative fuel swelling analysis. In FY17, six high resolution NRAD datasets of X486 experiment were acquired from INL. In FY20, 374 datasets/pins in 9 subassemblies were acquired from INL. Figure 2 shows an example of NRAD data: pin A866, A875, A876, DP64, DP60 and DP45 in X441 subassembly, which were recently incorporated into FIPD. The digitization of the raw NRAD data was also initiated in FY20. The NRAD data was originally in negative form, and was scanned into JPEG images at INL. After receiving the images at Argonne, the data were further converted into PDF format (consistent with other documents in FIPD) and uploaded to FIPD for user access. The current archived NRAD data is shown in Table 4.

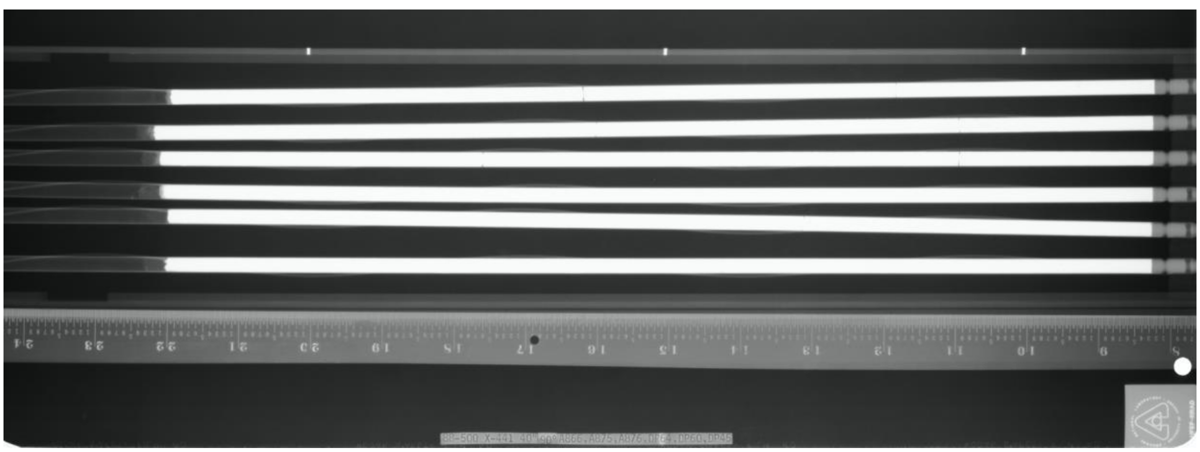


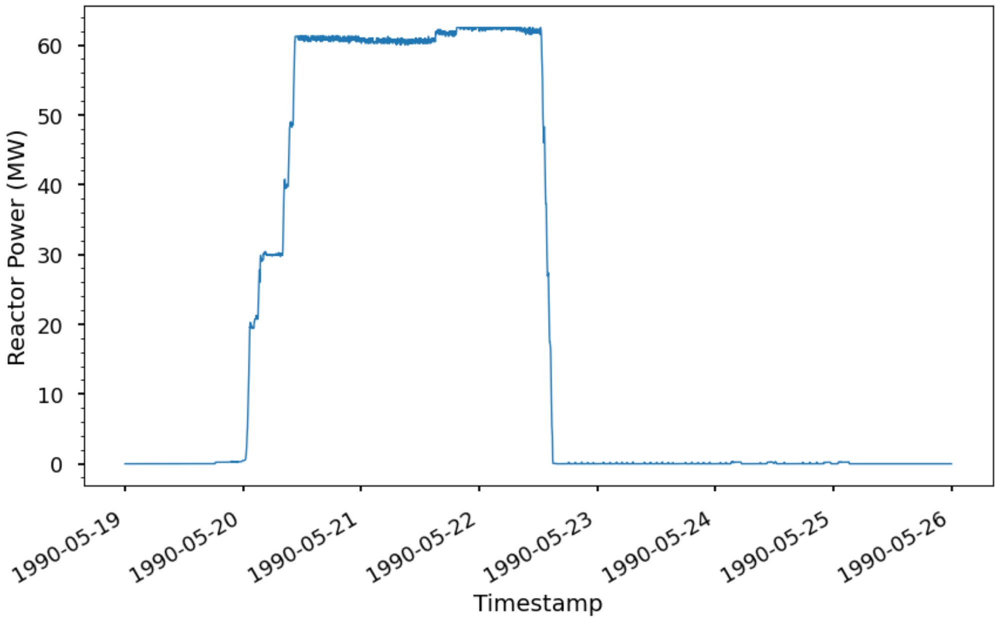
Figure 2: NRAD data for six pins (A866, A875, A876, DP64, DP60 and DP45) from the X441 subassembly.

Table 4: Current archival status of the high-resolution NRAD data.

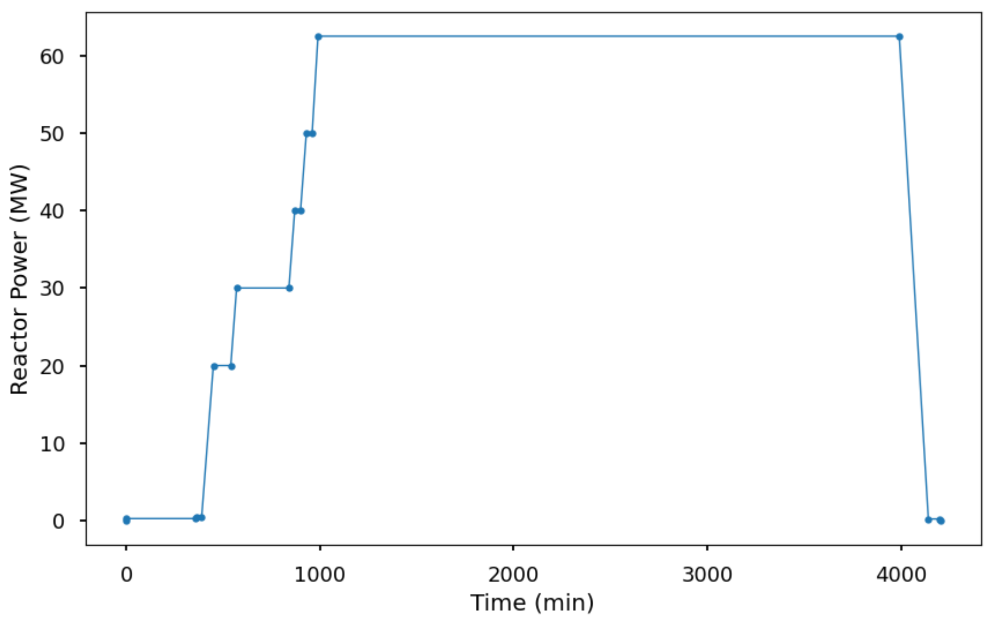
Experiment	Number of Pins in Hard Copy	Number of Hard-copy Datasets Examined by SME
X421	6	6
X423	37	37
X423A	37	37
X423B	37	37
X423C	37	37
X441	61	61
X441A	61	61
X447	49	49
X447A	49	49
X486	6	6
Total	380	380

2.3 Corrected Reactor Power History Data

The GLASS (Germanium Lithium Argon Scanning System) dataset was added to FIPD in FY19, and refined to be more user-friendly and useful in FY20. The GLASS system was installed in EBR-II to monitor and analyze the gamma activity of the reactor cover gas, and was useful in identifying the source of fission-gas leakage from fuel elements. The dataset contains daily 1-minute resolution recordings for Kr-85m, Kr-87, Kr-88, Xe-133, Xe-135, Xe-135m, and Xe138, as well as the total reactor power. The dataset contains 2785 daily records from May 12, 1986 (~Run139A) through January 2, 1994 (~Run167A). The total reactor power values in the GLASS dataset were not originally measured by the GLASS system, but were taken from DAS (Digital Data-Acquisition System) measurements using an ion chamber, and included in the GLASS dataset for comparison between power and gamma activity. The DAS power data included measurement error (both systemic and statistic) and required corrections that are based on the Run Reports to get the most reliable EBR-II power history. In addition, because of the 1-minute resolution, attempting to use the full DAS dataset in a fuel performance code, to account for the minor noise in the DAS data, would result in excessively long simulation run times. Thus, the corrected power levels are also simplified to facilitate fuel performance simulations. These simplified power histories are also provided for the EBR-II runs that did not have corresponding DAS power readings, based on the power histories provided in the Run Reports, which briefly describe the events and list day-by-day operating conditions. An example comparison is given in Figure 3. Both the original DAS data and the corrected/simplified power histories are available as a CSV file that can be downloaded through the FIPD interface.



(a)



(b)

Figure 3: Comparison of run history for EBR-II Run 154A. (a) Original DAS data, 1-minute interval data for 7 days, (b) Corrected and simplified power history, only data points at significant transition times.

Figure 4 provides an example comparison of each of the available histories in FIPD, showing that (1) as discussed in section 2.1, RCT run duration did not always provide the best power data for fuel performance, remedied by the addition of corrected-average and EMPT power conditions; and (2) DAS data include measurement errors corrected by the Run Report, remedied by the development of the simplified DAS histories.

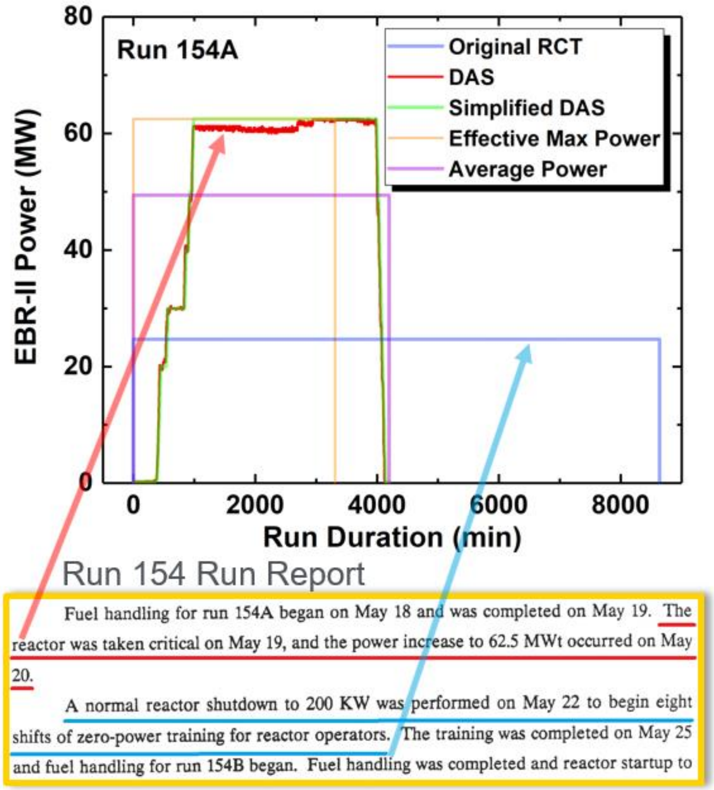


Figure 4: Example of smoothened power data (simplified DAS) vs. DAS data. Constant power run histories for original, corrected-average, and EMPT conditions are provided for comparison.

2.4 Subassembly Coolant Flow Rate

Subassembly coolant volumetric flow rates have been added to FIPD, for each subassembly, and each run, up to Run 168A. These flow rates are also provided along with the subassembly hardware type and hardware specifications, so that users can also determine mass flux using their own methodology if desired.

2.5 Pin Design Details

Pin design descriptions and as-built design specifications for each experiment were previously extracted from FIPD documentation and added to the relational database. Design data is available for all experiments except for X429. The design data fields for each pin design, as well as the measured fabrication data for each pin, are given in Figure 5. Values were not always documented for all fields in every experiment, but all values that were provided have been included.

Nominal Description	As-built Specification	Measured Fabrication Data
• Fuel composition	• Fuel length	• Element length
• Cladding type	• Fuel weight	• Element mass
• U-235 enrichment	• Fuel O.D.	• Fuel diameter
• Fuel O.D.	• Cladding O.D.	• Fuel length
• Fuel length	• Cladding thickness	• Fuel mass
• Fuel:Plenum ratio	• Element length	• Tag gas details
• Cladding O.D.	• Fuel/cladding diametral gap	• Sodium bond mass
• Cladding thickness	• Fuel density	• U/Pu/Zr isoptic masses
• Element length	• Smeared density	
• Smeared density	• Plenum/sodium volume	
• Wire wrap diameter/pitch	• Plenum:Fuel ratio	
• Sodium level above fuel	• Plenum gas composition	
	• U/Pu isotopic compositions	

Figure 5: Pin design description fields for nominal description and as-built specification, as well as measured fabrication data fields.

Design and fabrication data were originally available for viewing on the FIPD website, but have now been made available for download in a CSV format. This allows external tools to access all of the data for a pin in a simple key/value setup. This functionality has already been put to use in the ongoing FIPD-BISON integration project [12]. BISON's SmearedPelletMeshGeneratorFIPD module was developed to directly read the design CSV files produced by FIPD and generate an axisymmetric fuel-cladding mesh of the pin based on the available data for use in a BISON simulation.

3 BISON INPUT GENERATION

To facilitate BISON [13] simulations using the pin operating data in FIPD, the application was extended to provide a BISON input file generator, which can process the data for any pin into input files useable by BISON. For a complete BISON history of a fuel pin, five different CSV files are generated, which include: (1) time evolution of pin-averaged linear power; (2) time evolution of pin-averaged fast neutron flux; (3) axial peaking factor of linear power, both in normal form and cumulative distribution function (CDF) form; (4) axial peaking factor of fast neutron flux; and (5) time evolution of coolant mass flux. Each of these files is formatted to use one of BISON's PiecewiseLinear or PiecewiseBilinear function file formats, and can be included directly in a BISON simulation as downloaded from FIPD.

3.1 Time-Dependent Pin-Averaged Linear Power

Based on the simplified DAS EBR-II power history previously described in section 2.3, a time-dependent power correction factor was generated by referring to the RCT run duration and deposited energy. The power correction factor is normalized to ensure that the total deposited energy of each run is kept constant. For each run, the 30 axial point linear power data were used to generate the pin-averaged linear power. The product of the power correction factor and the pin-averaged FIPD linear power is the time-dependent pin-averaged linear power reported in the generated CSV file. A 1-second interval was added between EBR-II runs in the pin's time history.

3.2 Time-Dependent Pin-Averaged Fast Neutron Flux

Currently, only fast neutron fluence is directly reported in FIPD. However, fast neutron flux is important for fuel performance evaluation as it is involved in a series of radiation effects such as radiation creep and radiation-enhanced diffusion. Hence, time-averaged fast neutron flux values at 30 axial locations of each pin in each EBR-II run were first calculated by dividing the incremental fast fluence of that EBR-II run by the corresponding RCT run duration. A time-averaged and pin-averaged fast neutron flux value was then computed by averaging the 30 axial values. Assuming the fast neutron flux is proportional to reactor power in each run, the time-dependent power correction factors generated in the previous section were also used to generate the time-dependent pin-averaged fast neutron flux by multiplying the correction factor with corresponding pin-averaged fast neutron flux. As mentioned before, a 1-second interval was added between EBR-II runs.

3.3 Axial Peaking Factor of Linear Power

In the current BISON input file generator, the axial peaking factor of each pin is calculated based on the ultimate burnup (at the end of the last EBR-II run in which the pin was irradiated). This approach ensures that the calculated ultimate burnup using this axial peaking factor of linear power is consistent with the axial profile of the ultimate burnup reported in FIPD. Linear interpolation was used to provide dimensional data with a 5-mm interval (see Figure 6). The peaking factor is normalized so that the pin-averaged value is 1. The product of the peaking factor and the time-dependent pin-averaged linear power is the actual linear power at that axial location and time.

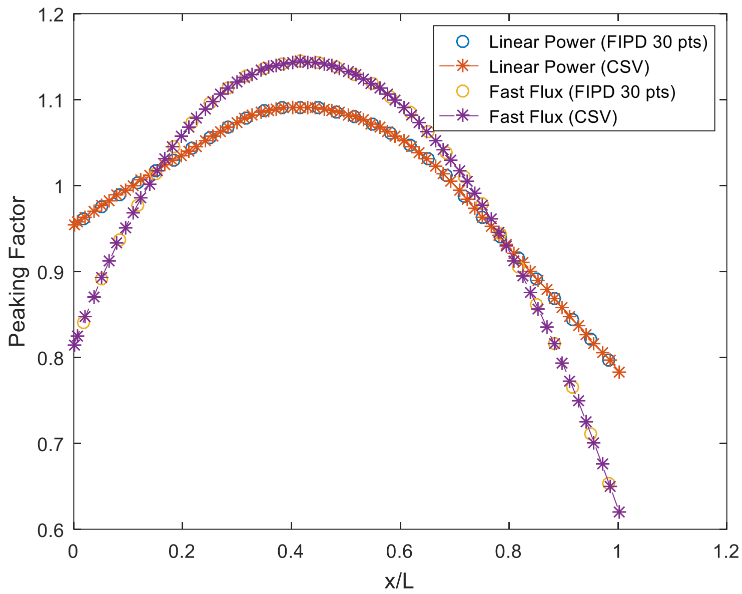


Figure 6: X447/DP11 peaking factor of linear power.

Previously, a generic coolant channel model was used by BISON for both light-water reactors (LWRs) and SFRs. Recently, a SodiumCoolantChannel module was implemented into BISON for sodium coolant to more accurately predict coolant temperatures for metallic fuels. The updated coolant channel model requires the power axial peaking profile to be provided as a cumulative distribution function (CDF). To accommodate this, FIPD also provides the linear power peaking factor in CDF form, alongside the original form. An example of this CDF form is shown in Figure 7.

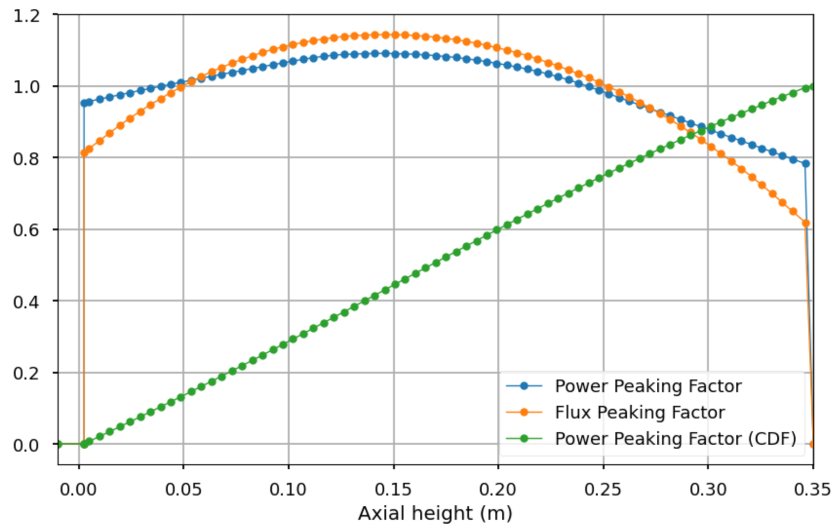


Figure 7: X447/DP11 power peaking factor presented as a normal axial profile, as well as in cumulative distribution function (CDF) form.

3.4 Axial Peaking Factor of Fast Neutron Flux

Similar to linear power peaking factor, in the current generator version, the axial peaking factor of each pin was calculated based on the ultimate fast neutron fluence (at the end of the last EBR-II run the pin was irradiated). This approach ensures that the calculated fast neutron fluence using this axial peaking factor of fast neutron flux is consistent with the axial profile of the ultimate fast neutron fluence reported in FIPD. Linear interpolation was used to provide dimensional data with a 5-mm interval (Figure 6). The peaking factor is normalized so that the pin-averaged value is 1. The product of the peaking factor and the time-dependent pin-averaged fast neutron flux is the actual fast neutron flux at that axial location and time.

3.5 Time-Dependent Coolant Mass Flux

Based on the limited available data, it is assumed that the subassembly coolant flow remains constant within each EBR-II run. The subassembly-specific coolant volume flow rate (in gallons per minute at 800 $°F$, gpm) of each run is available in FIPD. The volume flow rate can be converted to mass flow rate (kg/s) using the sodium density, 0.852 g/ml at 800 $°F$. In order to get the coolant flow mass flux values used by BISON's CoolantChannel module, the flow area of each subassembly involved must be used.

In IFR experiments irradiated in EBR-II, four different subassembly types were used: D-19, D-37, D-37A, and D-61 (see Figure 8). The subassembly hexagonal ducts of all these types have an identical flat-to-flat outer distance and wall thickness. Therefore, the only difference originates from the area occupied by fuel pins. The flow area of each subassembly setup can be estimated by subtracting the fuel pin area from the inner area of the hexagonal duct. Finally, by dividing the mass flow rate of each run by the corresponding subassembly flow area, the coolant mass flux can be deduced.

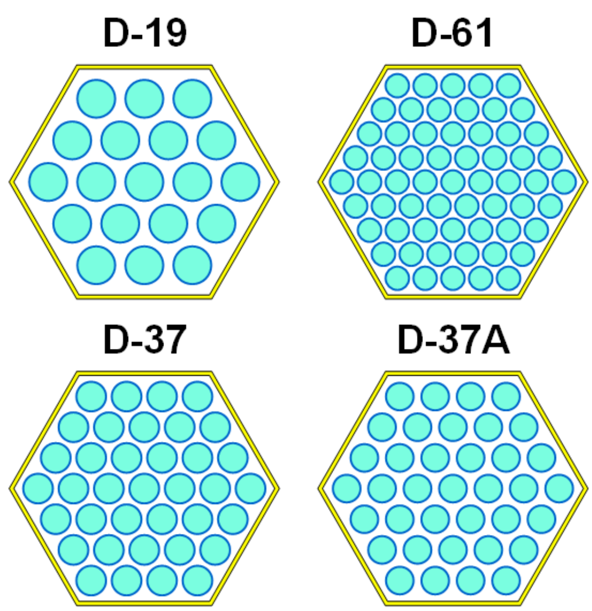


Figure 8: Schematic showing the four subassembly setups used in the IFR experiments.

4 EXTERNAL ACCESS

The breakdown of current users toward the end of FY20 is shown in Figure 9. FIPD is accepting requests for new users, with information about how to obtain access provided on the login page.

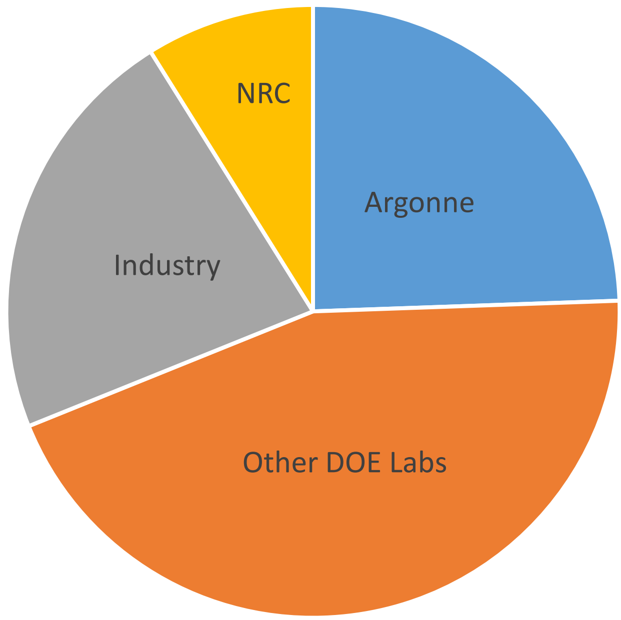


Figure 9: Distribution of current FIPD users, between Argonne, other DOE national labs, and industry entities.

5 FUTURE ACTIVITIES

Currently, the FIPD contains a majority of the key metallic fuel experiments data needed for supporting fuel behavior analysts and reactor designers, as well as supporting industry licensing activities for fast reactor designs that are based on metallic U-Zr fuels. The current mature state of the database will allow its immediate utilization to support those areas, as activities in both areas are expected to accelerate in the near future.

For example, the ongoing adaptation of the BISON fuel performance code to metallic fuel is at the state where it will require detailed validation and verification effort, especially as it is identified as a code of interest to both NRC and industry. The detailed data provided through the database is the type of data needed for BISON V&V activities, as well as supporting improvements in the code physics-based models. In addition, the ongoing development of the Versatile Test Reactor (VTR) that will utilize metallic U-Zr based fuel highlights the importance of the database and the quality of its data.

Recently, there have been industry stakeholders who are promoting different types of advanced fast reactor designs that are based on the US experience with metallic fuels in fast reactors. Those industries include TerraPower, GE-Hitachi, Oklo Inc., and Advanced Reactor Concepts (ARC), where some are already engaged in licensing discussions with the NRC. For example, Oklo Inc. is currently engaged in pre-application activities with the NRC for licensing their specific design, where metallic fuel performance and the qualification of metallic fuel data in the FIPD is key part of the discussion.

Finally, academic institutions, mainly domestic universities, desire access to metallic fuel data for engineering and scientific research. The restrictions on much of the data in FIPD does not allow for general access by users from universities. To accommodate these potential users, establishing a university access version of FIPD, with limited details and open literature information on metallic fuel, will be necessary, and will benefit fundamental fuel studies and advanced fuel designs.

Based on the above discussion, it is clear that the quality of the data accumulated in the FIPD is important to both analysts and industry, and QA will need to be a major part of future database related activities. The following is a summary of potential future FIPD activities:

- Continue revising data, including PIE images and graphs, in the database as original images become available from the original databook at Argonne or INL
- Include databooks for all available experiments from Alpha Gamma Hot Cell Facility (AGHCF) and databooks from Hot Fuel Examination Facility (HFEF) (as they become available), and QA related documents (especially HFEF related documents).
- Maintenance of the database software as described in the SQAPP (Software QA Program Plan).
- Make data available to analysts in NEAMS or other DOE supported programs.
- Support industry specific requests for data, and support the qualification of the data to meet NRC requirements for use in licensing related activities.
- Develop a website for general information on metallic fuels for advanced reactors, for supporting relevant engineering and scientific research in universities.

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Chemical & Fuel Cycle Technologies Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 208
Argonne, IL 60439

www.anl.gov

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